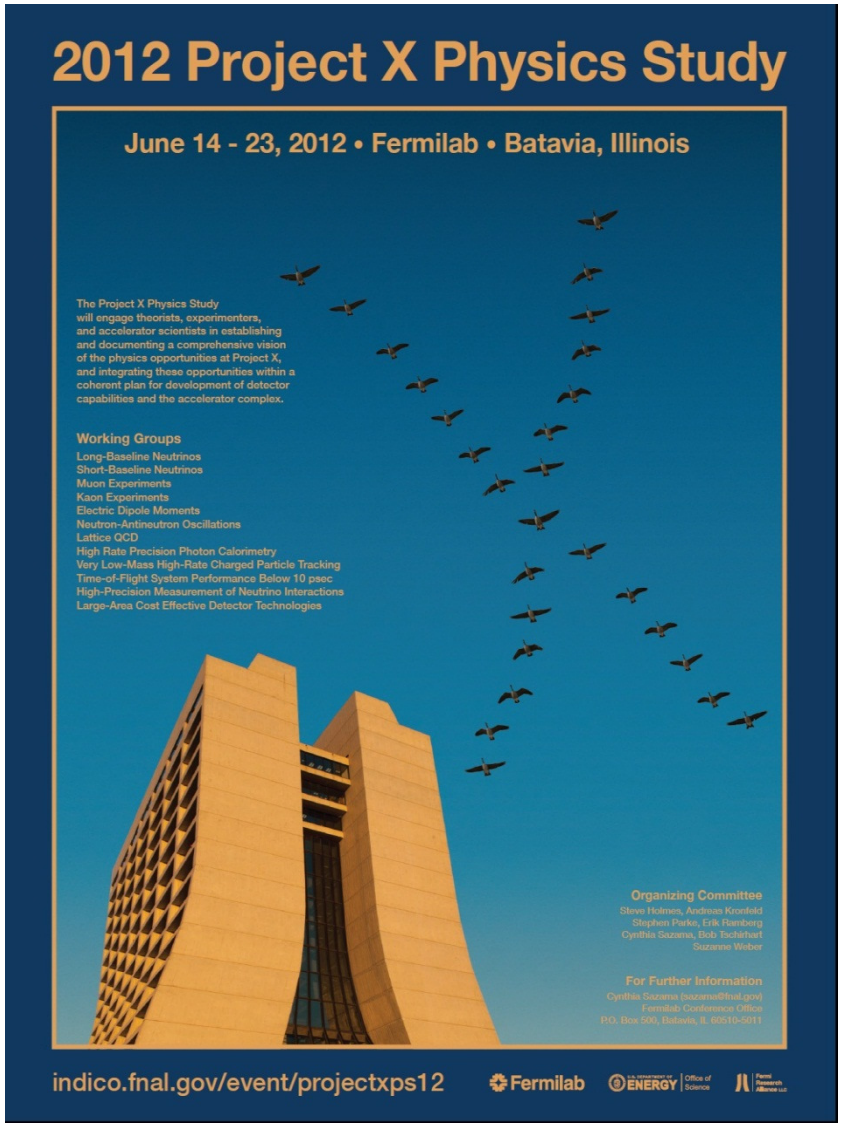
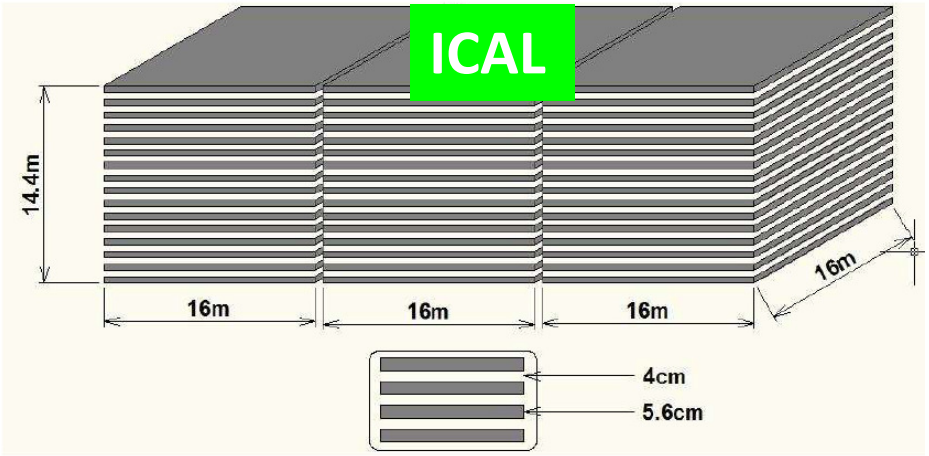


INO



Brajesh Choudhary

University of Delhi

for the INO Collaboration

What Is Known Known?

Forero, Tortola, Valle

arXiv:1205.4018v2

parameter	best fit $\pm 1\sigma$	2σ	3σ
$\Delta m^2_{21}\ [10^{-5}\mathrm{eV}^2]$	7.62 ± 0.19	7.27–8.01	7.12–8.20
$\Delta m^2_{31}\ [10^{-3}\mathrm{eV}^2]$	$2.53^{+0.08}_{-0.10}$ $-(2.40^{+0.10}_{-0.07})$	$2.34 - 2.69$ $-(2.25 - 2.59)$	$2.26 - 2.77$ $-(2.15 - 2.68)$
$\sin^2\theta_{12}$	$0.320^{+0.015}_{-0.017}$	0.29–0.35	0.27–0.37
$\sin^2\theta_{23}$	$0.49^{+0.08}_{-0.05}$ $0.53^{+0.05}_{-0.07}$	0.41–0.62 0.42–0.62	0.39–0.64
$\sin^2\theta_{13}$	$0.026^{+0.003}_{-0.004}$ $0.027^{+0.003}_{-0.004}$	0.019–0.033 0.020–0.034	0.015–0.036 0.016–0.037
δ	$(0.83^{+0.54}_{-0.64})\ \pi$ 0.07π [a]	$0 - 2\pi$	$0 - 2\pi$

Fogli et. al similar studies

- ✓ θ_{23} ---- *almost maximal*
- ✓ θ_{13} *is large* ---- $(9^0 \pm 1^0)$ ---- *MH determination to be easier*
- ✓ *Possibility of measuring CPV in the lepton sector opens up*

What Is Known Unknown?

- ***Neutrino Mass Ordering is Unknown***
- ***Certain hints of θ_{23} being non-maximal***
- ***If θ_{23} is non-maximal, which octant it occupies?***
- ***Whether CPV exists in the lepton sector?***

- ***What Atmospheric Neutrinos can do?***
- ***It can probe 1 and 2+3 above.***

Preliminary results from INO-ICAL simulation on its capabilities to resolve Neutrino Mass Ordering will be presented

India-based Neutrino Observatory

Salient Features

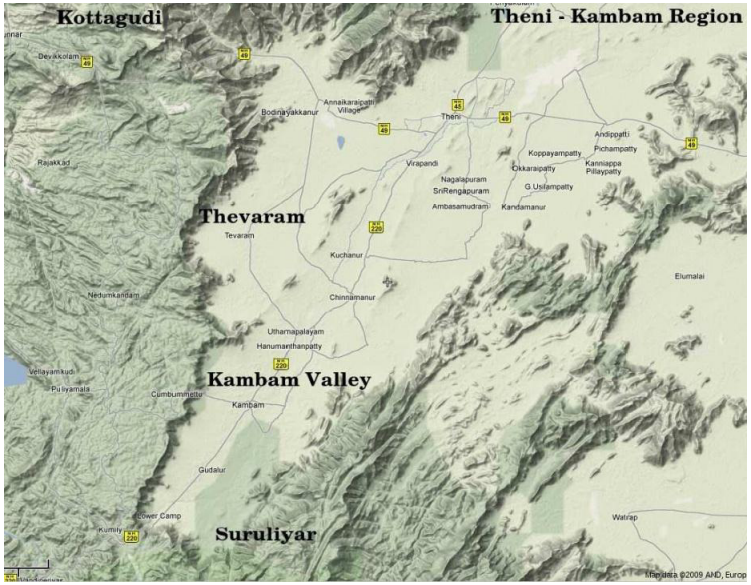
- ✓ ***Underground laboratory at Theni (9^0 58' N, 77^0 16'E) with ~1 km all-round rock cover accessed through a 2 km long tunnel. One large and several smaller caverns to facilitate many experimental programs.***
- ✓ ***Important neutrino issues, especially – mass parameters and other properties, will be explored in a manner complementary to on-going efforts in different parts of the world.***
- ✓ ***The ICAL detector, with its charge identification ability, will be able to address questions about neutrino mass ordering.***
- ✓ ***Distance from CERN, JPARC & RAL, close to "magic baseline". CERN-INO ~7300km, JPARC-INO ~ 6500km, RAL-INO ~ 7600km.***
- ✓ ***Once operational, in addition to ICAL, will support several other experiments, such as Neutrino-less Double Beta Decay and Dark Matter search experiments. Foreseen in near future.***
- ✓ ***INO facility - available to "International Community" for setting up experiments. You are*** MOST स्वागतम WELCOME

Status of the INO Project

Project approved by the Indian funding agencies

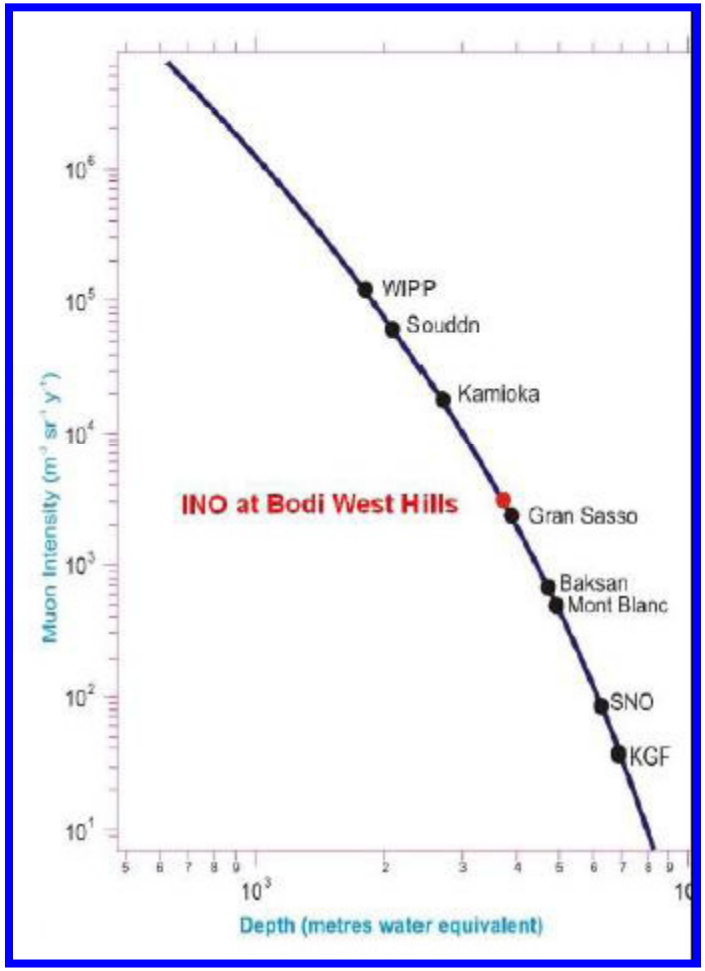
- *For INO Site - Environment and forest clearance obtained. 26 hectares of land at Pottipuram provided free of cost by the Tamil Nadu Govt. Construction of an underground laboratory and surface facilities near Pottipuram village in Theni district of Tamil Nadu.*
- *Construction of a 50kT magnetized Iron Calorimeter (ICAL) detector to study properties of neutrinos.*
- *Construction of INO center (a Detector R&D center) at Madurai. Land to be given against payment.*
- *Human resource development (INO graduate training program).*
- *Detector R & D.*

INO Site at Pottipuram

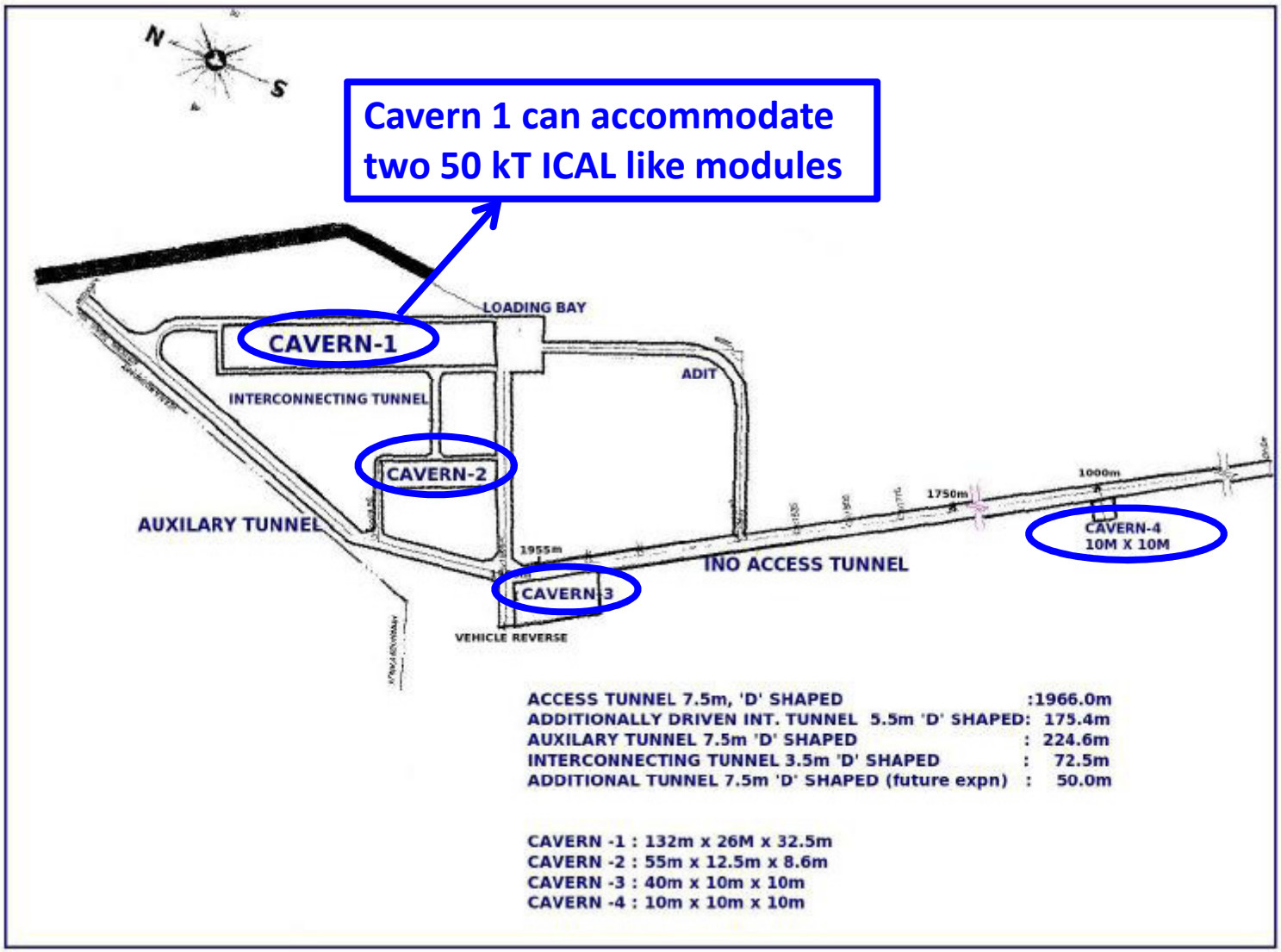


Salient Features of the Site

- All major components to be located underground. Flat terrain with good access from major roads.
- Rock quality is good. Cavern set in massive charnockite under the 1589 m peak. Vertical cover ~1289 meters. Tunnel length 1.97 km to reach the laboratory caverns from portal.
- Portal set outside the reserve forest boundary, hence no disturbance to forest . Tunnel and cavern under forest on the surface. Surface facilities not on forest land so no clearing of forest.
- Warm, low rainfall area and low humidity throughout the year. Unusual wind speeds during certain seasons.



Layout of the Underground Laboratory



INO-ICAL Experiment

A 50 kT magnetized Fe-RPC detector with charge identification

Physics Goals:

- ✓ ***Measure atmospheric neutrino parameters from distortion in L/E***
- ✓ ***Determine the sign of $|\Delta m^2_{31}|$ using matter effect***
- ✓ ***Measure the deviation of θ_{23} from 45^0 and its octant***
- ✓ ***Other Physics:***
  - ***Probe CP and CPT violation***
  - ***Constrain long range leptonic forces***
  - ***Study ultra high energy neutrinos and muons***

INO-ICAL Experiment

- ***Neutrino Source***
  - ✓ ***Need to cover a large L/E range***
    - ***Large L range (20 km – 12500 km)***
    - ***Large E_ν range (~2 GeV – 30 GeV (contained events))***
  - ✓ ***Use atmospheric neutrino as source***
- ***Detector Choice***
  - ***Should have large target mass (50 -100 kT)***
  - ***Good tracking and energy resolution (tracking calorimeter)***
  - ***Good directionality ($\approx$1 nsec time resolution)***
  - ***Charge identification for ν_μ and $\bar{\nu}_\mu$ separation***
  - ***Ease of construction***
  - ***Modularity***
  - ***Complementary to other existing and proposed detectors***
  - ✓ ***Use magnetized iron as target mass and RPC as active detector***
  - ✓ ***Iron Calorimeter (ICAL)***

  - ✓ ***Negatives – Poor electron sensitivity, relatively high threshold***

Current Status of INO-ICAL

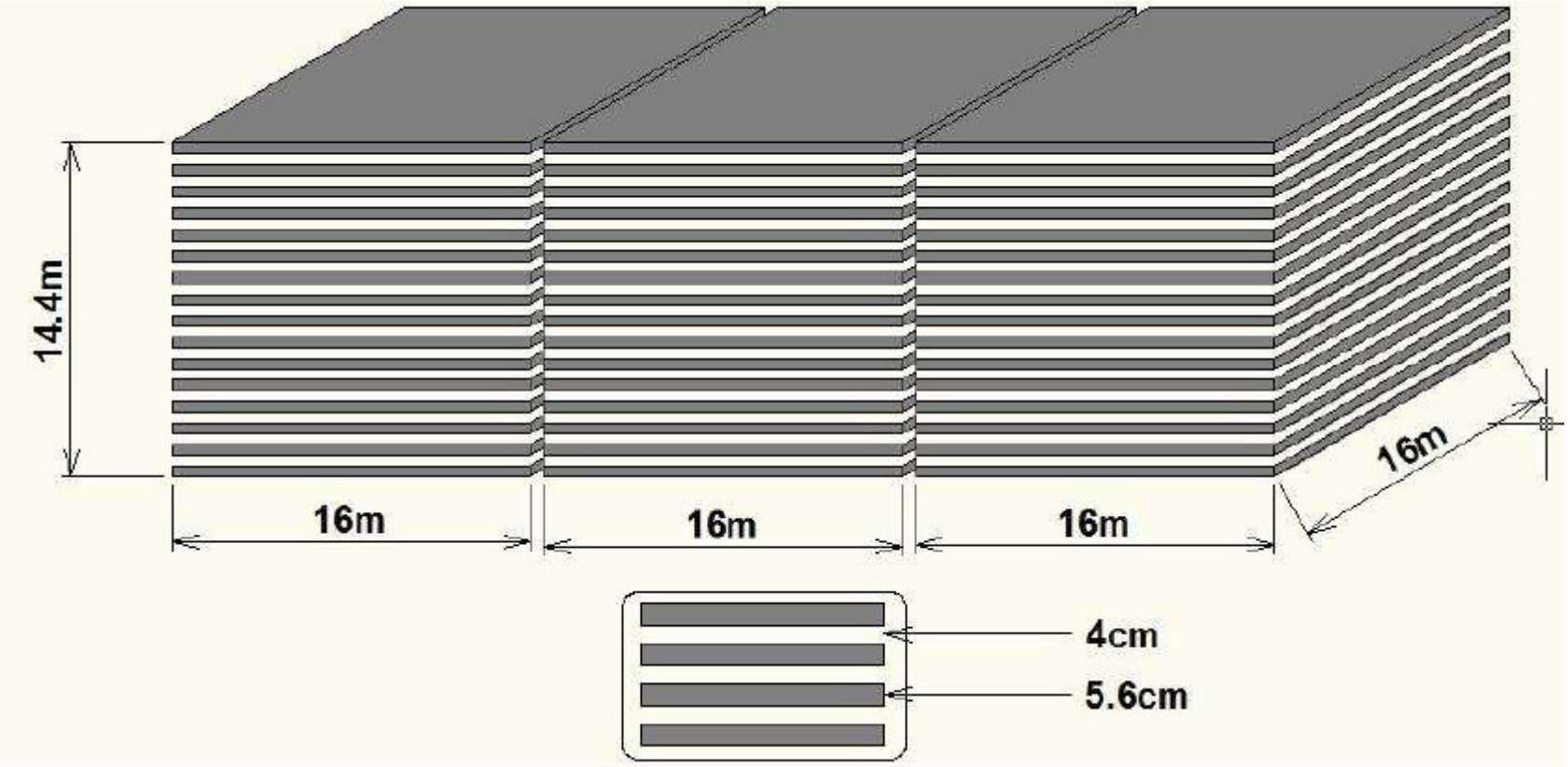
- ***RPC Development for ICAL***
  - ✓ *R & D almost complete*
  - ✓ *Full size RPCs (2m X 2m) are being fabricated not just in the INO labs but also by the industry*
  - ✓ *RPC production at large scale to be done by the industry*
- ***Electronics for ICAL***
  - ✓ *First batch of ASIC front end designed by the INO electronics team & fabricated by Euro Practice IC Services being tested in the RPC lab*
- ***Magnet for ICAL***
  - ✓ *Prototype magnet at VECC/SINP, Kolkota running. 2nd engineering module will be fabricated in next two years.*
- ***Simulation Studies in Progress***
  - ✓ *Preliminary results to be presented today.*
  - ✓ *White paper will be available shortly.*
- ***Human Resource Development***
  - ✓ *Graduate Training Program since 2008.*

INO Collaboration

Ahmadabad: Physical Research Lab.
Aligarh: Aligarh Muslim University
Allahabad: HRI
Calicut : University of Calicut
Chandigarh: Panjab University
Chennai :
IIT, Madras
IMSc
Delhi : University of Delhi
Guwahati : IIT, Guwahati
Hawaii (USA) : University of Hawaii
Indore: IIT, Indore
Jammu : University of Jammu

Kalpakkam : IGCAR
Kolkata :
Ramakrishna Mission
Vivekananda University
SINP
VECC and
University of Calcutta
Lucknow : Lucknow University
Madurai : American College
Mumbai : BARC
Mumbai :
IIT, Bombay
TIFR
Mysore : University of Mysore
Sambalpur : Sambalpur University;
Srinagar : University of Kashmir
Varanasi : Banaras Hindu University

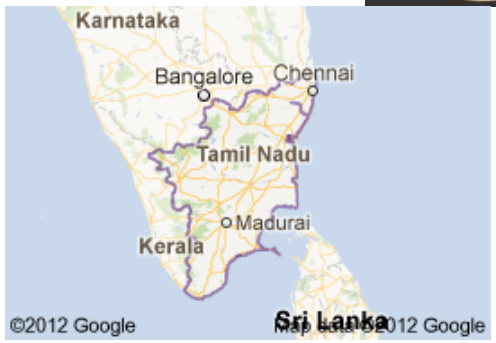
INO-ICAL Detector

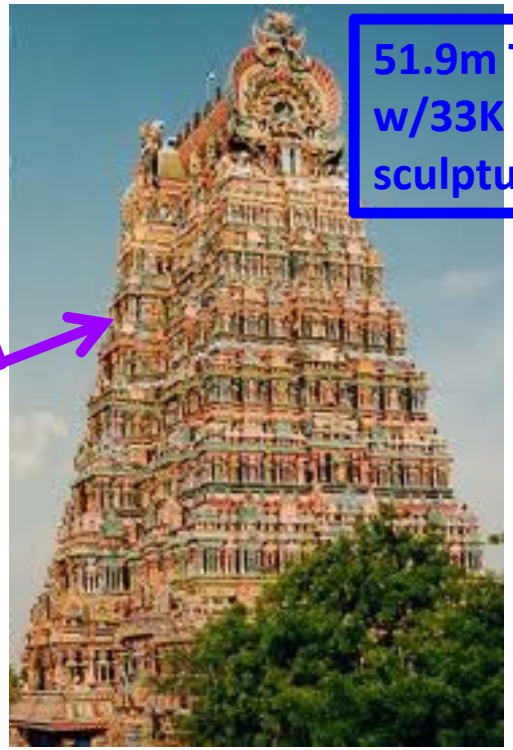


Detector Features

Number of Modules	*3*
Module Dimension	*16 m X 16 m X 12 m*
Detector Dimension	*48m X 16 m X 12 m*
Number of Layers	*140*
Iron Plate Thickness	*5.6 cm*
Gap for RPC Trays	*2.4 cm*
Magnetic Field	*1.3 T*
RPC Unit Dimension	*2 m X 2 m*
Readout Strip Width	*2 cm*
Number of RPCs/Road/Layer	*8*
Number of Roads/Layer/Module	*8*
Number of RPC units/Layer	*192*
Total number of RPC units	*~27000*
Number of Electronics Channels	*3.6 X 10^6*

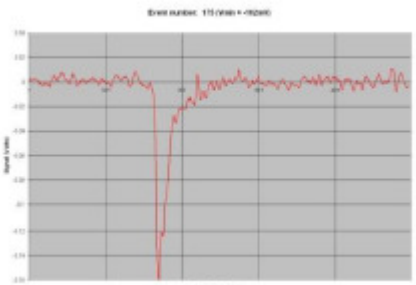
Location of INO within India



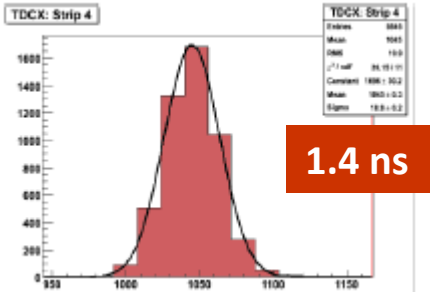


51.9m Tall w/33K sculptures

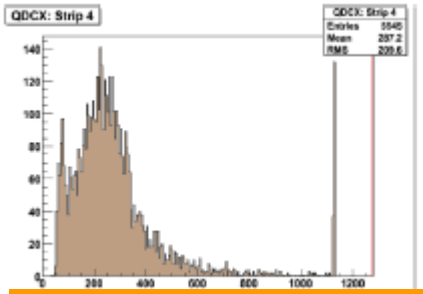
RPC R & D



Muon Pulse in RPC

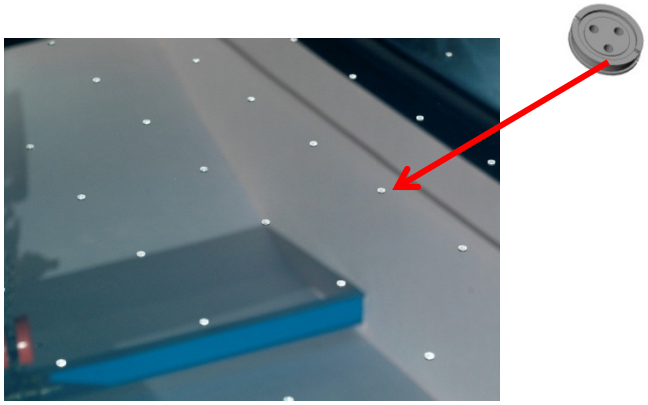


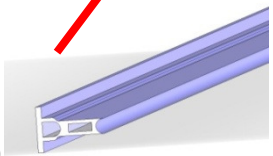
RPC timing resolution



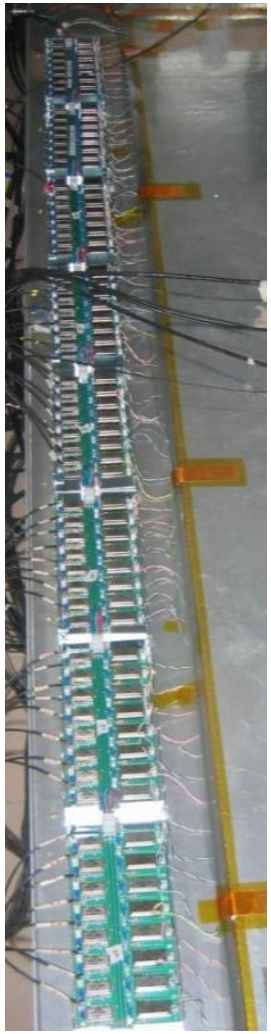
RPC Pulse ht. resolution

Fabrication of 2m X 2m Glass RPC



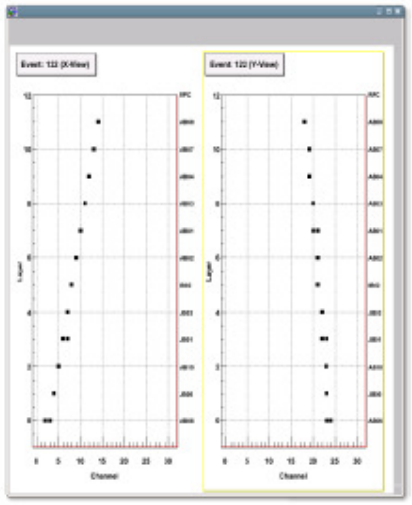


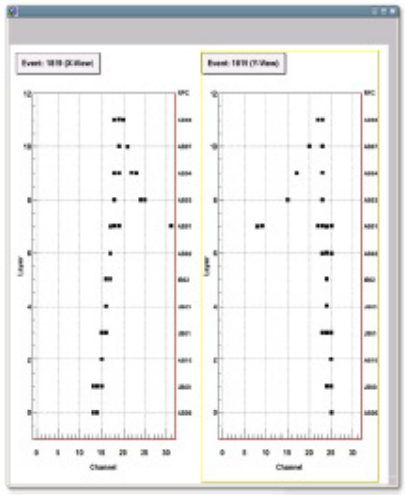
2m X 2m Glass RPC Test Stand

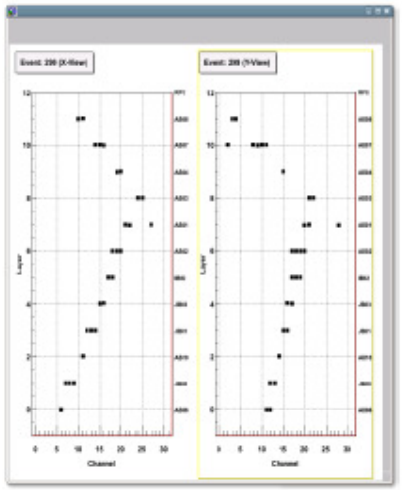


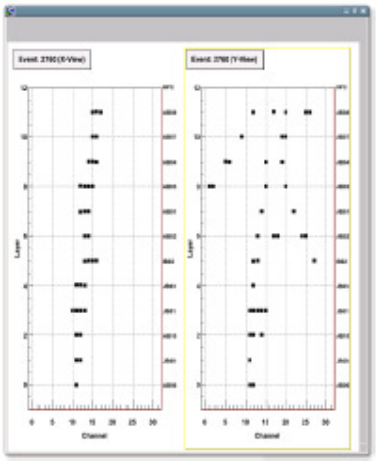
Some Interesting Cosmic Ray Tracks

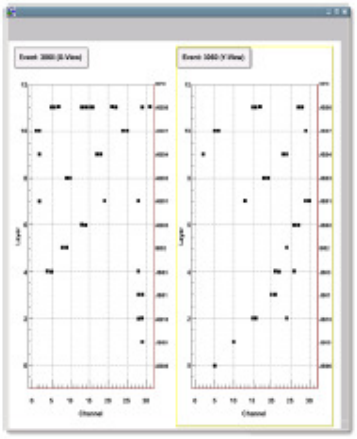
Shows the tracking capability of INO RPC system



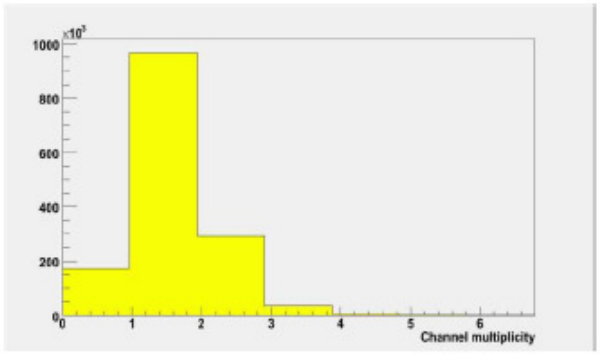




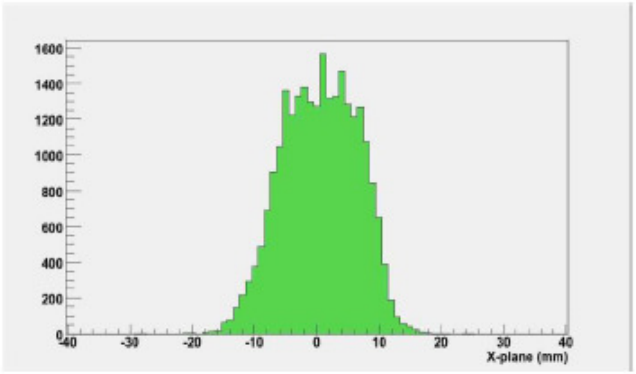




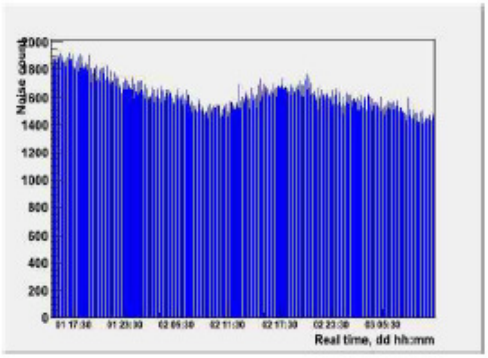
RPC Performance With Cosmic Rays



Strip Multiplicity due to crossing muons



Track residue in mm



Strip noise rate vs time

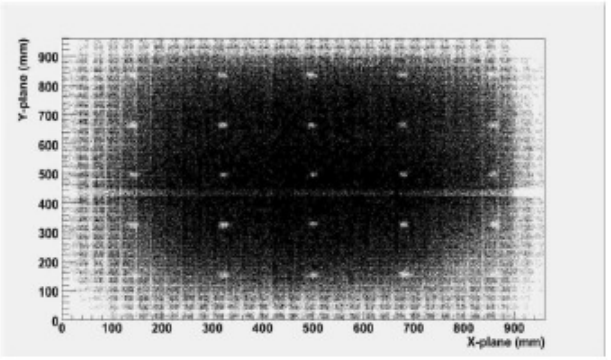
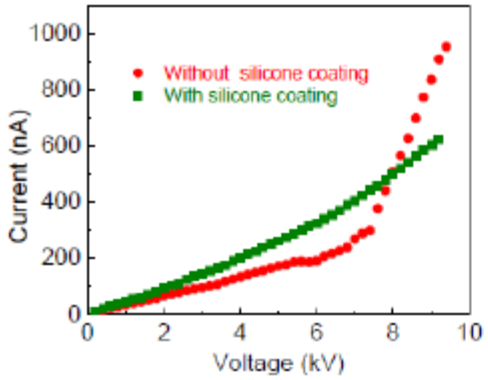
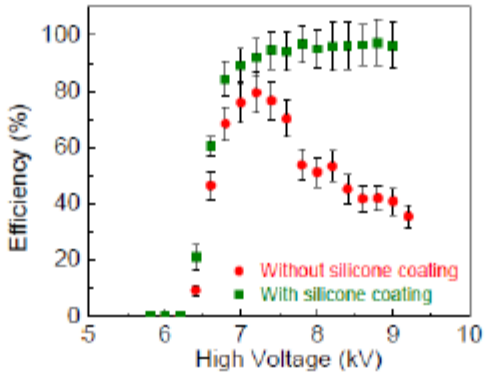


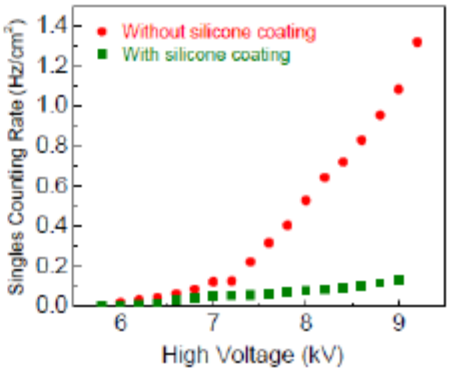
Image of a RPC using muons

Bakelite RPC R & D

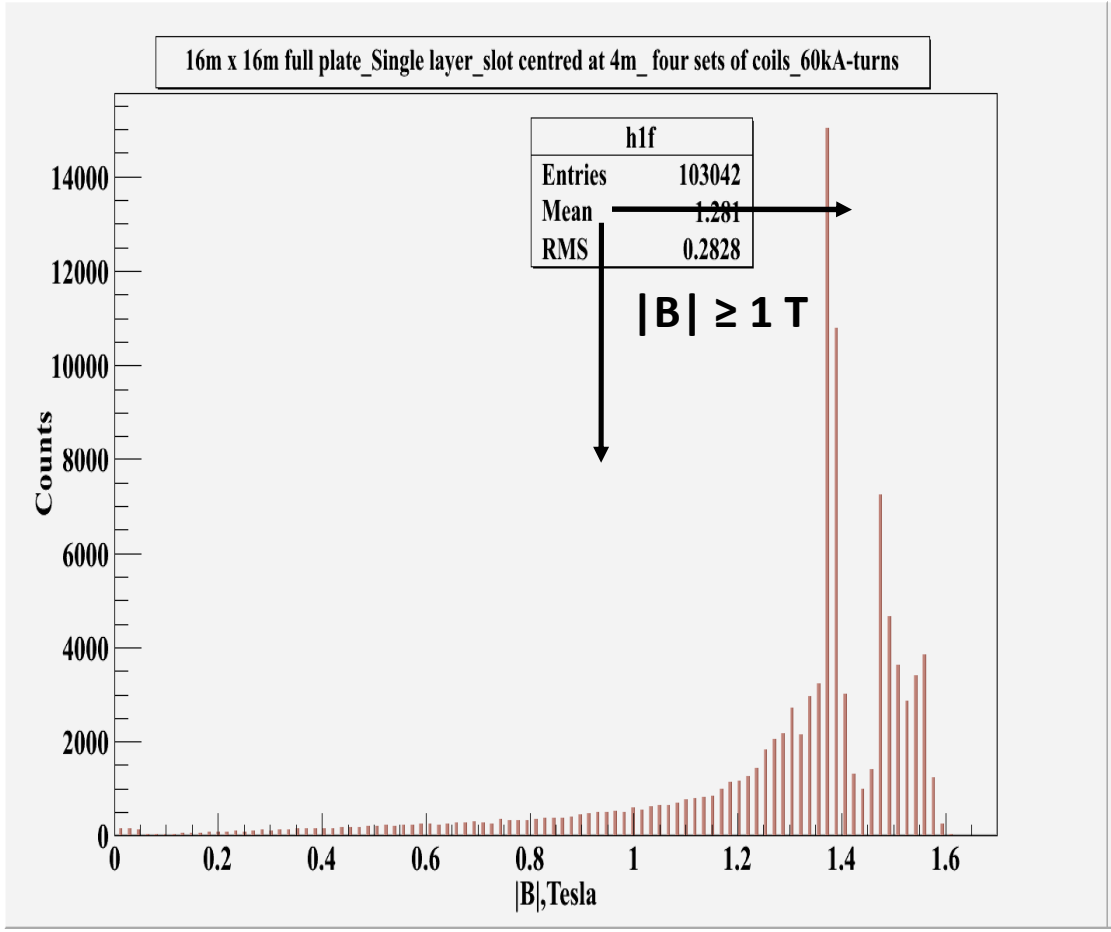
- ***SINP and VECC groups in Kolkata are involved in developing Bakelite RPCs operating in streamer mode***
- ***The inner surface of the Bakelite are coated with PDMS (silicone) to make the surface smooth***
- ***Efficiency plateau over 96% obtained with reduced noise rate and long term stability***
- ***INO-ICAL experiment being modular, can use both glass as well as Bakelite RPCs.***

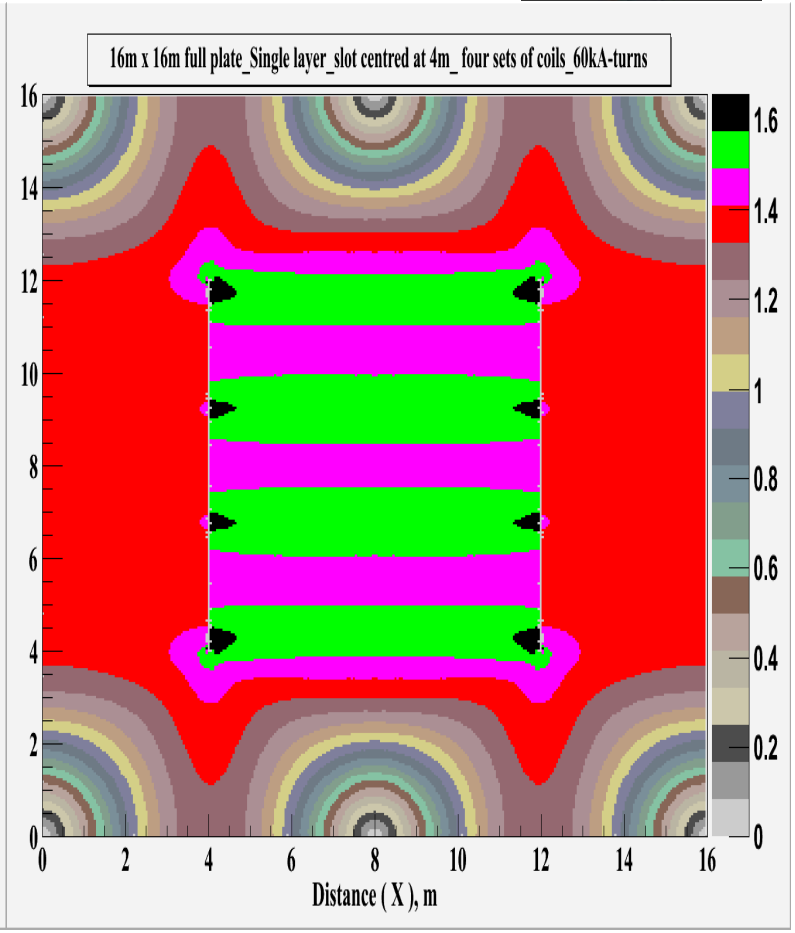




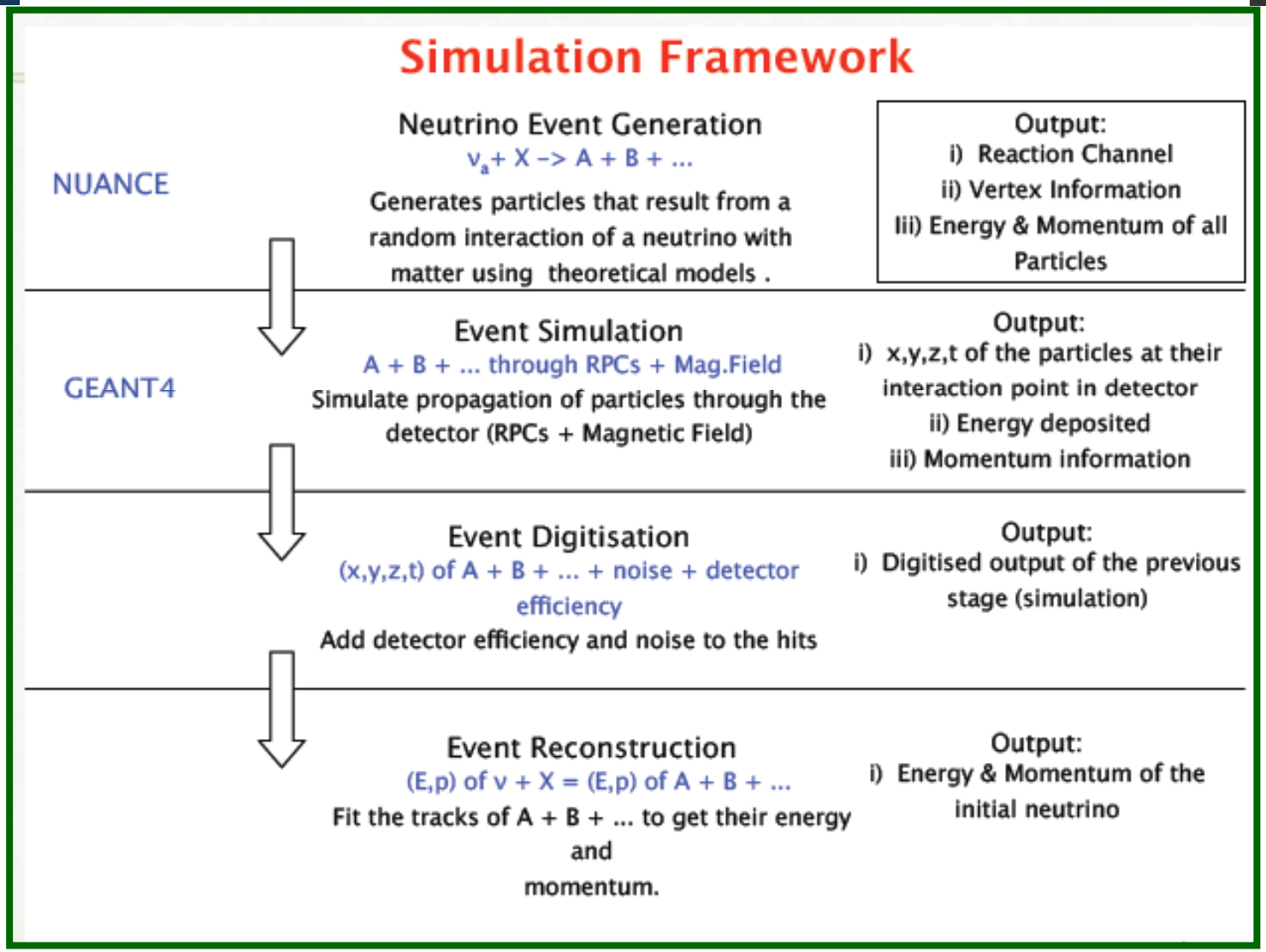


Magnetic Field Study

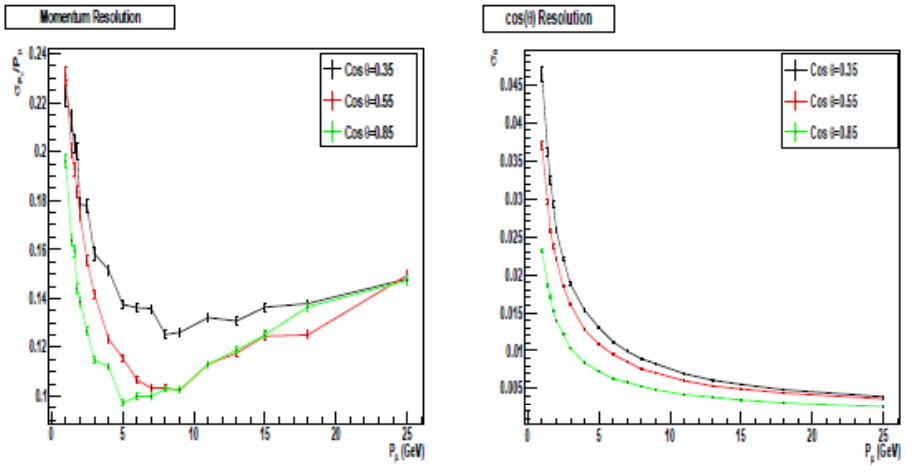


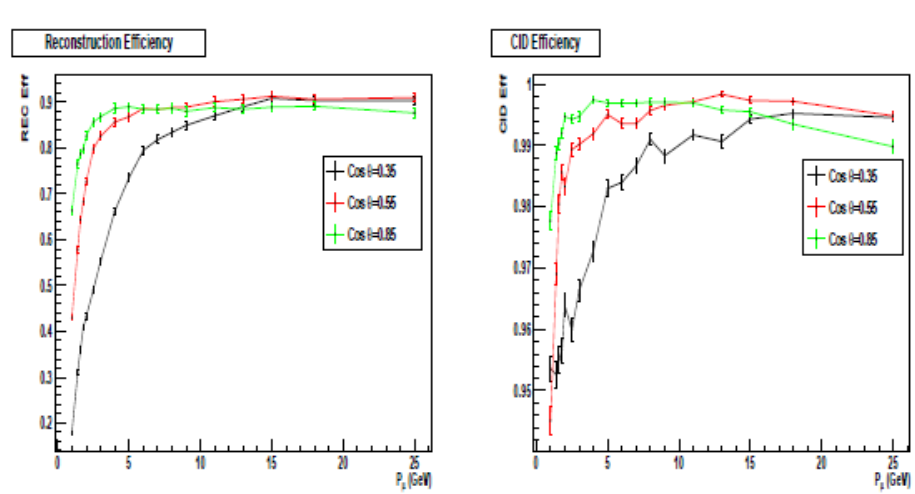


Simulation Framework



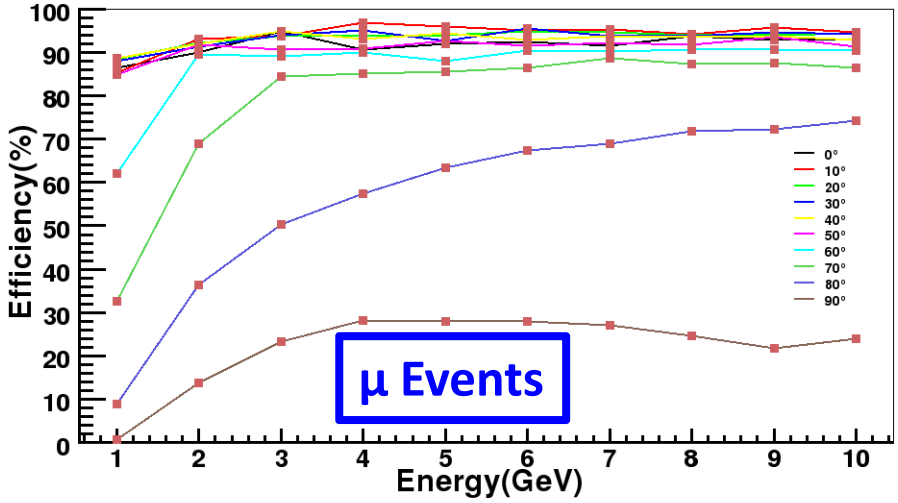
Detector Performance





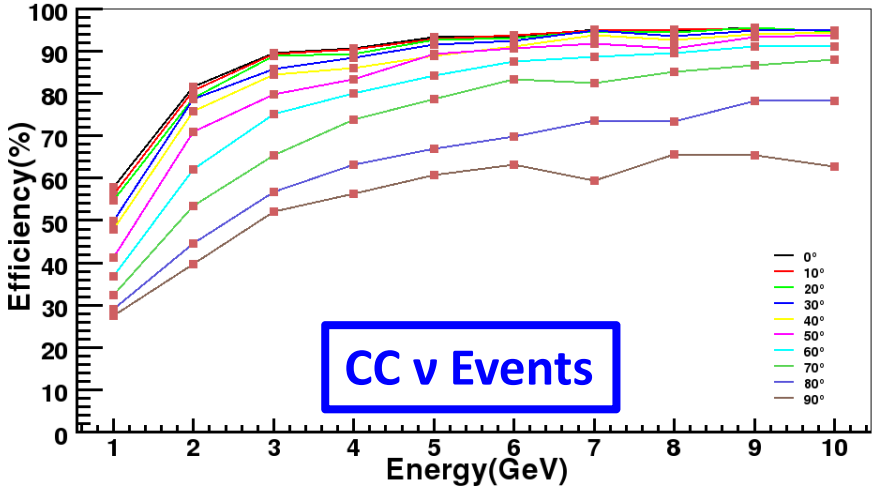
- *Inhomogeneous magnetic field mapping implemented into the ICAL code*
- *Effect of Iron thickness on efficiencies and charge id under study for optimization*
- *Resolution function for hadrons also obtained but not used in results shown here*

Simulation Results

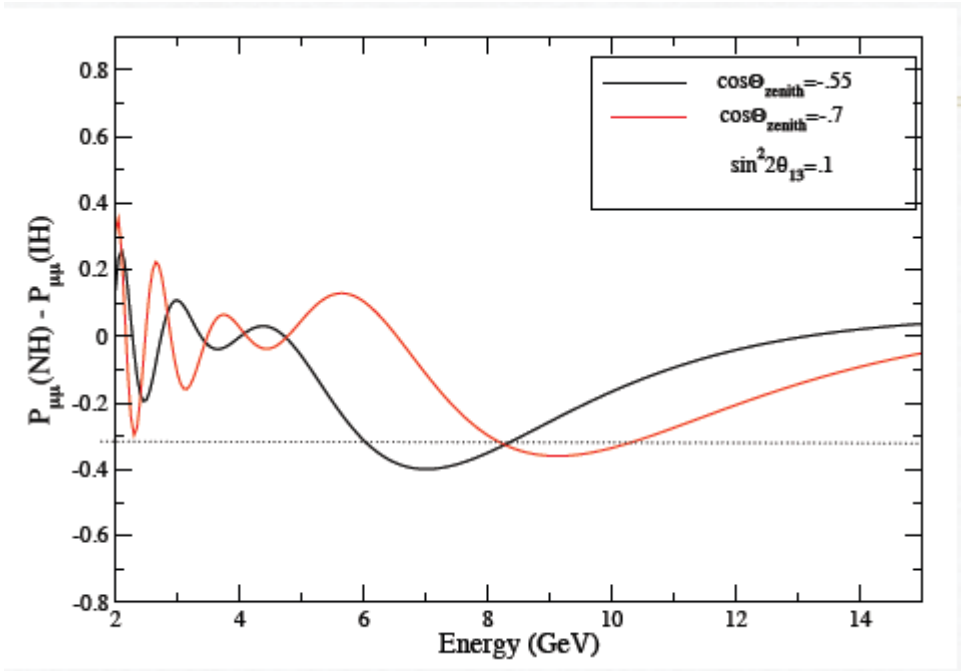


- Muon events and neutrino events are generated with event vertices randomly distributed over the fiducial volume of the detector
- Events are simulated using the INO-ICAL simulation code and the *Digitization* output is used to determine the trigger efficiency

- Analysis algorithm complies with the architecture of the trigger system.
- Trigger efficiency is determined for
  - Segment size 4m x 4m x 4m.
  - Trigger criteria
    - ✓ 1x5/8
    - ✓ 2x4/8
    - ✓ 3x3/8
    - ✓ 4x2/8

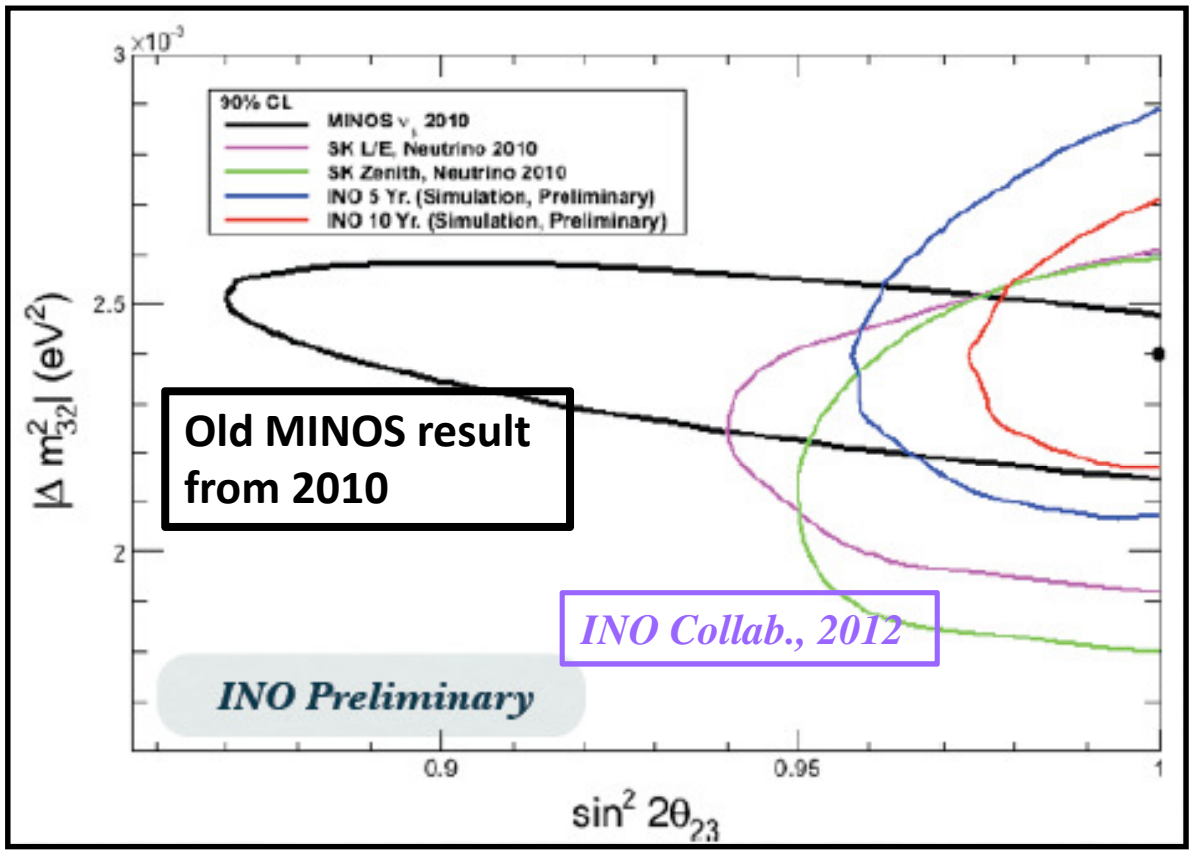


INO-ICAL Physics Reach



- ✓ *Matter effect fluctuates rapidly with Energy and cos θ_{Zenith}*
- ✓ *ICAL has good Energy and cos θ_{Zenith} resolution*
- ✓ *Matter effect will be opposite for $\nu\mu$ and $\bar{\nu}\mu$. INO-ICAL charge identification capability to resolves μ+ and μ-.*

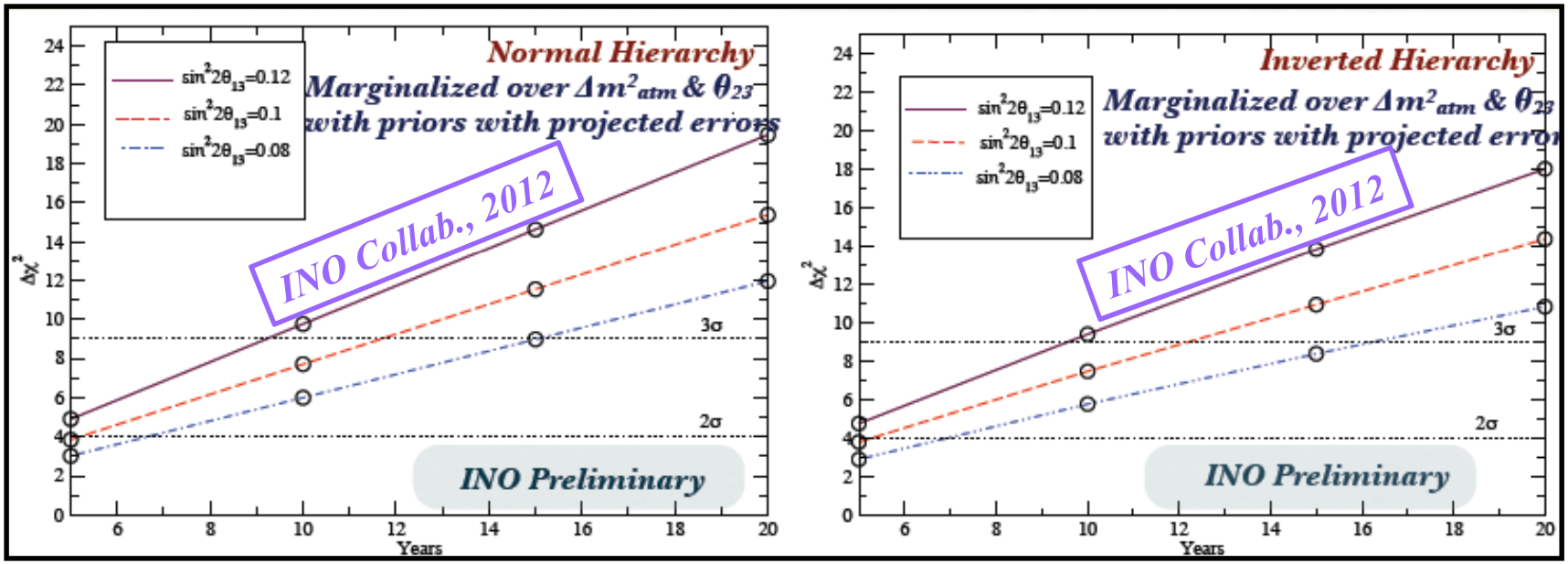
Atmospheric Parameters with INO-ICAL



- ***Precision not competitive with LBL experiments, but complementary***
- ***Use priors on $|\Delta m^2_{atm}|$, θ_{23}, θ_{13} from LBL + reactors projected reach***

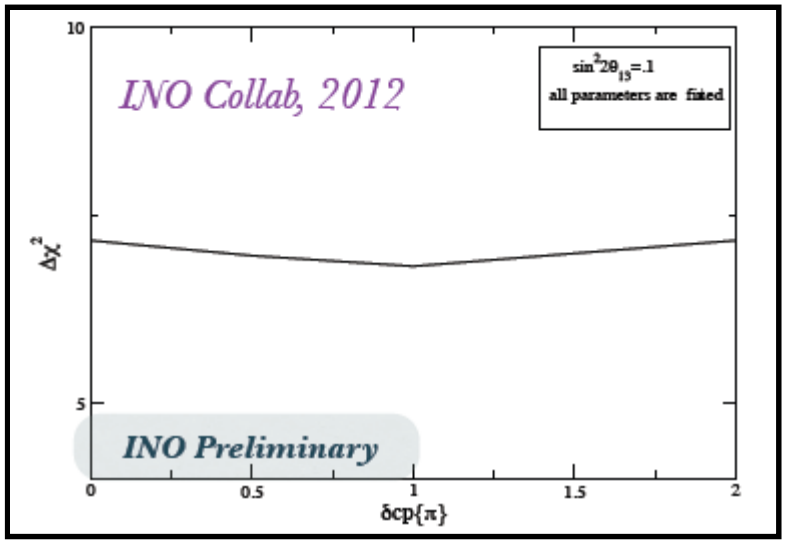
Mass Hierarchy with INO-ICAL

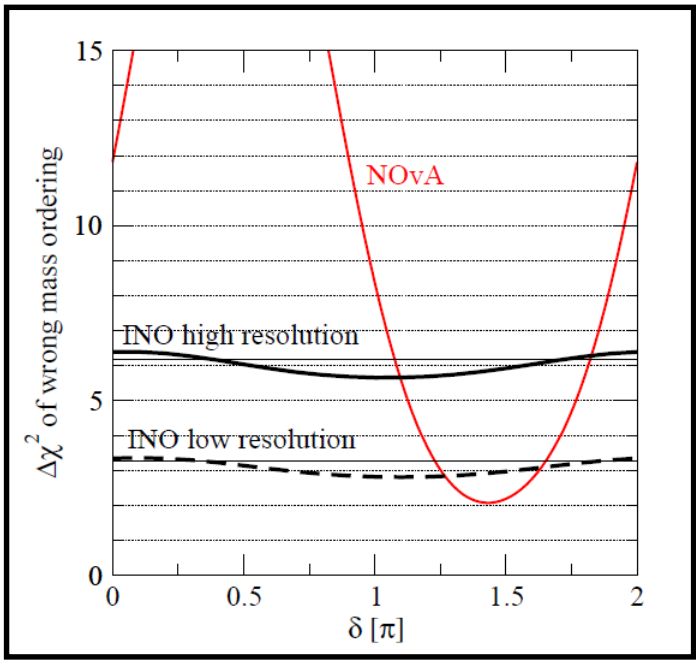
Events generated using Nuance & ICAL resolution in E and $\cos\theta_{zenith}$



~2σ sensitivity for $\sin^2\theta_{23}$ = 0.5, $\sin^2 2\theta_{13}$ = 0.1 by 2022 (5 yrs)
~2.7σ sensitivity for $\sin^2\theta_{23}$ = 0.5, $\sin^2 2\theta_{13}$ = 0.1 by 2027 (10 yrs)

Impact of δ_{CP} on Mass Hierarchy at INO





arXiv:1203.3388v1-Blennow, Schwetz

Data generated at δ_{CP} = 0 and fitted at non-zero δ_{CP}
INO will give Mass Hierarchy sensitivity almost independent of δ_{CP}

INO-ICAL Time LIne

SN	Description of work	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
	Civil work at Pottipuram						
1	Land acquisition and pre-project work						
2	Architectural and Engineering consultancy						
3	Tendering and award of contracts						
4	Mining of access portal						
5	Excavation of tunnel						
6	Excavation of caverns						
7	Installation of services, cranes, lifts etc.						
8	Civil work for magnet support bed						
9	Surface facilities						
	Magnet						
10	Procurement of steel plates						
11	Machining job for steel plates						
12	Transportation of machined plates at site						
13	Procurement of copper coils						
14	Assembly/erection of magnet (3 modules)						
	RPC						
15	Finalization of all design details, tendering						
16	Procurement of components						
17	Fabrication and assembly of 30000 pcs						
18	Transportation to site and tests						
19	Procurement of electronics, gas handling						
20	Installation and commissioning						

SUMMARY

- ***INO project is approved & funded. Site has been selected and environmental clearance given.***
- ***Work on INO laboratory to begin soon.***
- ***Detector R&D for INO-ICAL almost complete.***
- ***Large scale detector fabrication to begin with the help of industry.***

- ✓ ***Large θ_{13} is positive news for resolving neutrino MH.***
- ✓ ***INO-ICAL will play an important role in resolving MH.***
- ✓ ***INO should be able to resolve MH at ~2σ by 2022 (250 kT-yr) and ~2.7σ by 2027 (500kT-yr).***

Thanks to Naba Mondal and Sandhya Choubey for providing the latest INO simulation results

THANK YOU